SYSTEM OVERVIEW AND PRELIMINARY TEST RESULTS OF THE ESS BEAM CURRENT MONITOR SYSTEM

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Abstract

The ESS Linac will include in total 21 Beam Current Monitors, mostly of ACCT type, to measure the average current over the 2.86 ms beam pulse, the pulse charge and the pulse profile. It is also planned to use a few Fast Current Transformers to check the performance of the fast beam choppers with a rise time as short as 10 ns. In addition to the absolute current measurement, the BCM system needs to measure the differential beam current and act on the Machine Interlock System if the difference exceeds some thresholds. The differential current measurement is particularly important in the low energy part of the Linac, where Beam Loss Monitors cannot reliably detect beam losses. This paper gives an overview of the ESS BCM system and presents some preliminary test results with a commercial ACCT and MTCA.4 electronics.

INTRODUCTION

The BCMs (Beam Current Monitors) of the ESS Linac will be primarily used to measure beam current and charge, but they will also provide input to the BIS (Beam Interlock System) and may also be used for the synchronization of the target wheel to the beam arrival time [1]. Table 1 summarizes the main parameters of the ESS proton beam and the BCM requirements (these parameters need to go through a refinement process and may change in the future).

Table 1: ESS Beam Parameters and BCM Requirements

Max beam energy	2	GeV
Pulse repetition rate	14	Hz
Pulse duration	2.86	ms
Max pulse current (nominal beam)	62.5	mA
Min pulse current	6.25	mA
RF frequency	352, 704	MHz
BCM accuracy (nominal beam)	+/-1	%
BCM resolution (nominal beam)	< 1	%
BCM response time	< 1	µs
Beam pipe diameter	60, 100	mm

It is planned to install mo st of the BCMs in the low energy end of the Linac (see Fig. 1) where BLMs (Beam Loss Monitors) cannot reliably measure beam losses. In addition to the absolute current measurement, some of the BCMs will be configured for a differential current measurement. In the later case, the current difference between two BCMs will be measured and compared to a user-defined threshold. If the absolute or the differential current exceeds its threshold, a signal will be sent to the BIS for a fast beam abort with a total response time of less than 10 µs. The differential current measurement is particularly important during the commissioning phase to detect large and sudden beam losses and shut the beam off to avoid any damage.

It is planned to use ACCTs (AC Current Transformers) for most of the BCMs. These devices can be used to measure the pulse profile with a measurement rise/fall time of a few hundred ns. In addition to the ACCTs, it is planned to use a few FCTs (Fast Current Transformers) wherever a faster response is required. The FCT has a bandwidth up to a few GHz and can be used, for example, to measure the performance of the MEBT (Medium Energy Beam Transport) choppers.

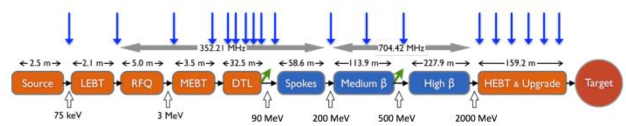

Figure 1: Distribution of the current monitors along the ESS linac.

TESTS WITH AN ACCT PROTOTYPE

A Bergoz ACCT was chosen for the tests. The ACCT hardware consists of a toroid with a high-permeability core, a power supply and an analogue module where the ACCT signal is filtered and conditioned. Table 2 summarizes the main ACCT specifications [2].

ACCT Tests without Readout Electronics

The ACCT was primarily tested without connecting it to data acquisition electronics. A waveform generator was used to generate a 2.86 ms, 50 mA rectangular pulse with a repetition rate of 14 Hz passing through the toroid. The output of the electronics was then examined for measuring the response time, droop, linearity, bandwidth and noise.

Fig. 2 shows the ACCT settling time of less than 1 µs from the start of the current pulse.

The lower cutoff frequency of the ACCT is about 3 Hz resulting in a droop of 4.2% with a 2.86 ms pulse as shown in Fig. 3.

As the output signal of an ACCT has no DC component (it cannot measure DC currents), the baseline voltage during the no-pulse period becomes negative so that the average voltage always stays at zero volt. The mA-equivalent of the baseline voltage just before the start of

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the pulse is measured at -4.6 mA for the 2.86 ms, 50 mA pulse. The negative baseline voltage appears as an error in the measurement, unless compensated by the readout electronics.

In all these measurements, the results were in agreement with the ESS requirements and the ACCT specifications.

Table 2: Specifications of the Bergoz ACCT

Input current	±100	mA
Output full scale	±5	V
Lower -3 dB cutoff freq.	3	Hz
Upper -3 dB cutoff freq.	1	MHz
Droop	< 2	%/ms
Slew rate	2	V/µs
Output offset	0.5	mV (max)
Noise at 100 mA full scale	< 20	µA (rms)
Power Supply	±5, 100	V, mA
Connectors	Sensor: BNO Elect. in: BNO Elect. out: BNC	

ACCT Tests with Readout Electronics

In the next stage, the ACCT was connected to a prototype MTCA.4 (Telecommunication Computing Architecture for Physics Research [3]) data acquisition system, thus providing the user with the possibility to digitally process the ACCT data and monitor the measurement results on a GUI (Graphical User Interface) running on a remote console. The MTCA.4 system, which was used for these tests, consists of the following parts:

- 019 chassis from Schroff
- Telkoor power module
- NAT MCH
- Gen. 2 CPU unit from Concurrent Technologies
- SIS8300 AMC from Struck
- SIS8900 RTM from Struck

The output signal of the ACCT electronics was fed into a DC-coupled input of the SIS8900 RTM (Rear Transition Module) and then sampled and fed into the onboard FPGA of the SIS8300 AMC (Advanced Mezzanine Card) communicating to the EPICS control system. The ADC clock was set to 88 MHz and the data acquisition was synchronized with the current pulse using an external 14 Hz trigger.

Fig. 4 shows a screenshot of the ACCT GUI with a graphical view of the pulsed current and its specifications, being: average current, charge per pulse, cumulative charge and baseline level. The GUI is refreshed at 2 Hz approximately.

The integration of the ACCT into the ESS EPICS control system was mainly done by Cosylab. The integration software consists of a SIS8300 kernel driver (supplied by Struck), as well as a user-space driver, an EPICS application and a GUI supplied by Cosylab.

A few functionalities were added later on to the GUI to improve its usability. That includes algorithms for droop compensation, DC level correction and a moving average filter for noise reduction.

The ACCT system has been put into operation since several months with the purpose of identifying any errors in the MTCA.4 crate or the software. The system has been running successfully and no problem has been detected during this period except a few small bugs in the software, which are currently removed.

FUTURE WORKS/IMPROVEMENTS

In the current version of the ACCT system, the entire digital signal processing after the A-D conversion is done by the computer running the GUI. Although this worked well in the preliminary tests for monitoring purposes, it is not a fast and reliable method for acting on the BIS, nor data capture on the AMC. It is therefore planned to transfer part of the digital processing such as droop compensation, synchronization to the trigger input, DC level correction and filtering to the FPGA of the digitizer card. This, on one hand, makes the signal processing much faster, and on the other hand, reduces the computing load of the console computer.

It is planned to use two 14 Hz triggers from the ESS timing system to mark the start and the end of the pulse, thus synchronizing the data acquisition with the repetition rate of the Linac. A MRF (Micro Research Finland) timing system has been configured by the ICS (Integrated Control System) division to generate the triggers. The option of providing an external clock for the ADC sampling is currently under discussion with the ICS division.

Differential current measurement and providing a fast input to the BIS will be one of the first ACCT functionalities needed for the commissioning of the low energy part of the Linac. For that purpose, it is planed to use two inputs of the digitizer card to measure the beam current at two BCM locations. The FPGA will therefore be programmed to compare the two current levels, and in case the difference exceeds a user-defined threshold, send a pulse to the BIS for a fast beam abort. Technical details for the implementation of this system are currently being discussed with the ESS ICS division and the MPS (Machine Protection System) group.

A post-mortem data capture mechanism is planned to be implemented at a later stage. In that case, the most recent ACCT data will be stored in a buffer implemented on the local AMC memory. The data can then be retrieved and examined upon a user request or machine failure. Trigger signals required for capturing the ACCT data will be provided by the ESS timing system.

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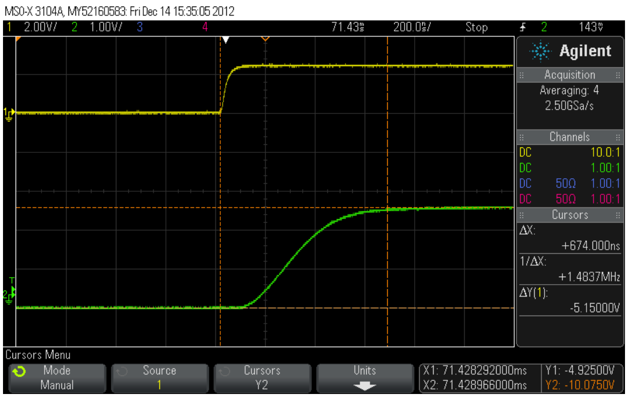

Figure 2: Current pulse (above) and output signal of the ACCT electronics (below) with a settling time of 674 ns.

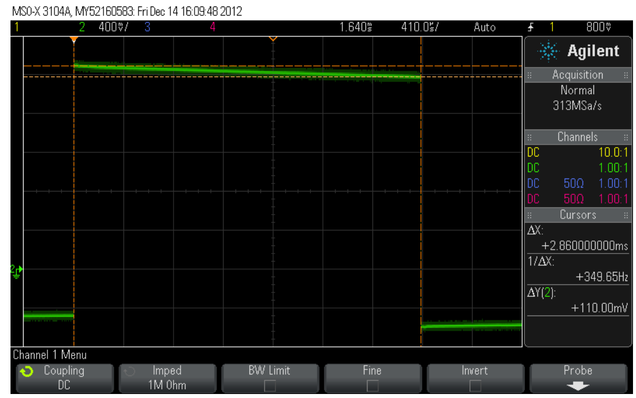

Figure 3: The ACCT droop with a 2.86 ms pulse measured at 4.2%.

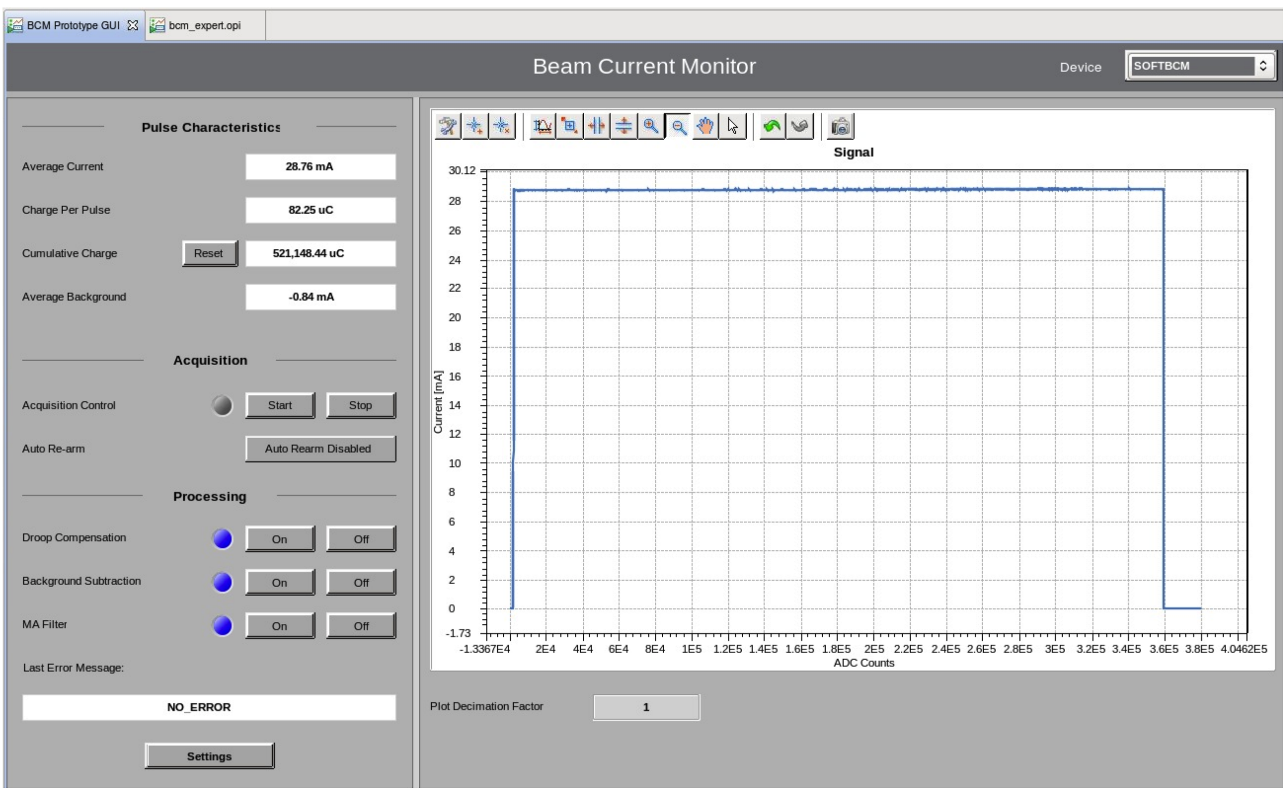

Figure 4: Screenshot of the ACCT GUI showing the current pulse specifications and profile.

SUMMARY AND CONCLUSIONS

The BCM system of the ESS Linac will be mainly based on ACCTs. However, a few FCTs may also be used wherever a faster response is required. The BCM system will be primarily used for monitoring the beam current and charge, but it will also provide input to the Machine Interlock System in case the absolute or the differential current exceeds user-defined thresholds. The differential measurement is particularly important in the low energy part of the Linac where BLMs cannot reliably measure beam losses. A BCM prototype based on a commercial ACCT and MTCA.4 electronics has been procured and integrated into the ESS EPICS control system and tested with promising results. The system will be improved by programming the on-board FPGA of the digitizer card to perform the required digital signal processing including differential current measurement and post-mortem data capture, as well as providing a fast input to the Machine Interlock system.

REFERENCES

[1] ESS Technical Design Report, 13 Nov. 2012
[2] Bergoz Instrumentation, AC Current Transformer User's Manual
[3] http://www.picmg.org/

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